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by  
F. F. Kitze

Miscellaneous Paper 18  
September 1957

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SEP 1957

INSTALLATION OF PILES IN PERMAFROST

by

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1. Introduction. The use of pile foundations for supporting buildings and other engineering structures in regions of permafrost is gaining recognition among construction agencies. The pile type foundation is particularly adaptable to areas where the permafrost consists of fine grained, frost susceptible soils having a high ice content. Foundation designs which require subsoil excavation for placement of a gravel base and construction of footings and slabs are generally not suitable for this particular soil condition because site disturbance has a detrimental effect on the thermal balance in the underlying permafrost. A condition of degrading permafrost in fine grained soil containing ice will normally cause substantial foundation settlement which could result eventually in complete failure of a structure. A refrigerated type of foundation is one scheme for supporting structures on frozen fine grained soils, but the construction of foundation cooling and freezing systems is costly. The use of piles offers a practical and economical method of foundation construction. The installation of foundation piles can be accomplished

without undue disturbance to the site, thus preserving the existing thermal regime in the frozen subsoil, and preventing the detrimental effects associated with degrading permafrost.

2. Background. There was no known widespread use of pile foundations in Arctic and Subarctic Alaska prior to 1950. Early application of the pile type foundation in Alaskan permafrost areas was limited primarily to bridge foundations constructed by the Alaska Railroad and the Alaska Road Commission. A few buildings at outlying communities were supported on piles. This limited use of pile foundations may be attributed, in part, to the general lack of engineering knowledge regarding pile load carrying capacity, pile stability, and pile installation methods as related to permafrost.

In the summer of 1952, a study of foundation piles installed in permafrost was initiated at the Fairbanks Permafrost Research Area, Fairbanks, Alaska, as part of a continuing program of research directed toward the development of design criteria for construction on frozen ground. The Fairbanks Permafrost Research Area is under the direction of the Arctic Construction and Frost Effects Laboratory, U. S. Army Engineer Division, New England, Boston, Massachusetts. The purpose of the pile study was to determine the feasibility of various pile installation methods, ascertain factors affecting pile stability, and to develop criteria related to load carrying capacity of piles embedded in permafrost. The installation, observation, and testing of piles was started in 1952 and is continuing at the present time. This paper is a summary of experiences at the

Fairbanks Permafrost Research Area in connection with methods for installing piles in permafrost. /

3. Site Conditions. The Fairbanks Permafrost Research Area is located approximately 2-1/2 miles northeast of Fairbanks, Alaska. The mean annual temperature at Fairbanks is about 26° F with extremes of minus 55° F to plus 90° F. The natural soil underlying the Research Area is principally silt to a depth of approximately 50 ft with a variable content of organic material and occasional layers of peat. The gradation range of the silt subgrade is shown on Photo No. 1. Ice lenses are present throughout the silt. The annual frost zone varies from 2 to 6-ft under natural surface cover conditions and the thickness of the permafrost layer is in the range of 150 to 180-ft. The permafrost temperatures vary from about 28° F to 32° F under natural surface cover conditions.

4. Installation of Piles. A total of 230 test piles have been installed to date at the Research Area. These piles consisted of several types, namely; timber, precast concrete, steel pipe, I-beams, wide flange sections, and bearing pile sections, with depths of installations ranging from 4 to 16-ft in permafrost. Under the initial pile test program in the summer of 1952, a total of 64 test piles was installed at the Research Area. Between 1953 and 1957, a total of 73 additional test piles was installed either as additions to the original test pile site or as foundation piles for Research Area test structures and utilities. A new test site consisting of 93 test piles was constructed in April of 1957.

5. Installation Methods. Five different methods have been employed for installing test piles at the Research Area:

Steam Thawing	16 Piles
Driving	27 Piles
Water Drilling w/ Rotary Drill	33 Piles
Churn Drilling and Driving	43 Piles
Power Auger	111 Piles
<hr/>	
Total	230 Piles

a. Steam Thaw Method. The steam thawing procedure consisted of advancing a steam point or jet through the frozen soil to the desired pile depth and then continuing the flow of steam until a hole of the desired diameter had been thawed around the steam jet. Steam was supplied from a Cleaver-Brooks, oil fired, 3-car heater, Model D-S. (See Photo No. 2). The steam jet was a 21-ft length of 3/4-in. pipe (See Photo No. 3). During steam thaw operations, the steam pressure at the boiler was 80 psi and the steam temperature at the boiler was 265°F with an average jet steam temperature of 220°F. The pile was installed in the thawed hole immediately following the steaming operation. Photo No. 4 shows a completed pile installation. All steam thawed piles were embedded approximately 16-ft into permafrost.

b. Driving Method. Driven piles consisted of 8-in. diameter, open-end, standard weight steel pipe driven to embedments ranging from 4 to 16-ft in permafrost. Pile driving was accomplished with

pile driving equipment. Nine piles were driven using a drop hammer arrangement and 18 piles, using a conventional double acting pile hammer.

(1) Drop Hammer Driving. The drop hammer driving arrangement is shown in Photo No. 5. The equipment consisted of conventional leads mounted on a crane. All handling of the pile and raising of the pile hammer in the leads was performed by crane. Photo No. 6 is a close-up view of the drop hammer which weighs 1350 lbs. No protective cap was used on the pipe piles during the driving operation, resulting in some damage to the pile tops. Photo No. 7 shows a damaged 8-in. pipe pile after driving to a depth of 8-ft into permafrost.

(2) Double Acting Pile Hammer Driving. Photo No. 8 shows pile driving operations using a McKiernan-Terry No. 7, double acting pile hammer powered by compressed air. The compressed air was furnished by a Chicago pneumatic air compressor, rated at 500 cfm. The pile hammer was handled with a Hyster Crane. A steel cylinder, 2-ft in length and 12-in. in diameter, was tack welded in the hammer guides at the base of the hammer. This steel cylinder fitted over the top of the pile and served to support the hammer in a vertical position in the driving operations. A removable protective cap was used on each pile to prevent damaging the pile top. (See Photo No. 9). Photo No. 10 shows a test pile driven 16-ft into permafrost with no visible damage to the pile top.

c. Water Drilling Method. A field designed wash-cutting barrel, adapted to a Longyear Rotary core drill, was used to drill test pile holes ranging in permafrost depth from 6 to 16-ft. The wash-cutting barrel, shown in Photo No. 11, is a 12-in. in diameter, steel cylinder with a wall thickness of 1/2 in. and a 3-ft length. The bottom edge of the barrel is serrated to provide a cutting edge, and the top of the barrel is fitted with an adapter to attach N-type drill rod used with the Longyear core drill. Photo No. 12 shows the cutting barrel adapted to the Longyear rotary core drill. Water is circulated to the cutting barrel through the drill rod which facilitates cutting the frozen soil and removal of cuttings as the barrel is advanced. The initial barrel design was inadequate for advancing the hole because a core of frozen soil was left intact within the barrel. The frozen core could not be lifted with the barrel nor readily destroyed by water circulation. The barrel was subsequently modified to provide a means of destroying the frozen soil core in the barrel (See Photo No. 13) by providing cutting edges of fins within the barrel near the bottom edge. The interior cutters, shown in Photo No. 13, sufficiently destroyed the soil core to permit removal of the material by water circulation. All pile holes drilled by the wash-cutting barrel method were "bailed" of excess water prior to pile installation.

d. Churn Drilling and Driving Method. Piles installed by churn drilling and driving consisted of 4-in. diameter, open-end

standard steel pipe with embedment in permafrost ranging from 10 to 16-ft. Photo No. 14 shows the Cyclone Churn Drill, No. 40, used at the Research Area. The pile installation procedure consisted of churn drilling a pilot hole of slightly smaller diameter than the pile using a conventional churn drill chopping bit. (See Photo No. 15). The pipe piles were then driven through the pilot holes by means of drive blocks attached to the churn drill tools. The driving operation is shown in Photo No. 16. The pilot holes were drilled to within 3-ft of the desired pile depth and then firmly seated by driving to the final depth without benefit of the pilot hole. Photo No. 17 shows a group of foundation piles installed at the Research Area using this method.

e. Dry Augering Method. The dry augering method consists of utilizing a conventional power auger for boring pile holes into permafrost. A typical power auger is shown in Photo No. 18. Test pile holes ranging in depth from 6 to 21-ft in permafrost were bored with the power auger. Hole diameters ranged from 10 to 18 in. Photo No. 19 shows a typical auger bit fitted with special removable carbide cutters to permit sharpening and hardness treatment. Photo No. 20 shows augering operations with a 14-in. diameter bit. Frozen soil cuttings are removed from the hole on the auger bit in a single upward movement of the auger stem or "Kelly bar". Upon removal from the hole, the speed of rotation of the auger bit is increased suddenly to remove the soil cuttings. Cleaning of the auger bit is facilitated by manual contact of a shovel while the bit is rotating. Cleaning

of the bit following an auger run requires only several seconds. The auger stem or "kelly bar" on the auger, shown in Photo No. 18, was of sufficient length for augering to a depth of approximately 21-ft below the ground surface without the use of drill stem extensions. Photo No. 21 shows a portion of a pile test site constructed at the Fairbanks Research Area in which 93 test piles were installed by this method.

6. Pile Backfill Methods. Pile holes formed by steam thawing, dry augering and water drilling methods were made 4 to 6 in. larger in diameter than the nominal pile diameter to provide an adequate annular space between pile and wall of hole for placement and consolidation of backfill material. The majority of test piles installed in pre-formed holes at the Research Area were backfilled with silt-water slurry. Clay-water slurry, dry sand, and water were also employed as backfill materials. The pile backfill was performed as soon as possible following completion of a pile hole.

a. Slurry Mixing and Placement. Soil-water slurries were mixed and placed by both manual procedures and power equipment. Whenever possible, the soil removed during drilling or augering of a pile hole was mixed with water and the resultant slurry used as pile backfill in the same hole. The coldest available water was used for mixing with the soil to produce the coldest possible slurry placement temperature.

A substantial number of piles were backfilled using manual procedures for mixing and placing the slurry. (See Photo No. 22).

Slurry was mixed in a large mortar box by shovel and hoe and then "dumped" into the annular space around the pile from pails or from a wheelbarrow. The slurry was rodded constantly during placement to eliminate potential void spaces along the pile.

Pile backfill was also accomplished using conventional concrete equipment for mixing and placement of soil-water slurries. Photo No. 23 shows the slurry mixing equipment. The small concrete mixer was mounted on a 6 by 6 truck to provide mixer mobility. The mixing operation was performed adjacent to the pile where the auger cuttings from the particular pile hole were shoveled directly into the mixer. Following mixing, the slurry was "dumped" on the ground surface near the pile and then shoveled into the pile hole. Each mixer batch of slurry provided approximately 4-ft of pile hole backfill. The 4-ft lifts were consolidated by vibration using a gasoline engine driven spud type, concrete vibrator. (See Photo No. 24). Photo No. 25 is a close-up view of the 1-1/2-in. vibrator spud.

b. Other Backfill. Other backfill materials used for Research Area test piles consisted of dry sand and water. Photo No. 26 shows dry sand backfill operations. The sand was shoveled into the hole in vertical lifts of 3 to 4-ft. Each lift was consolidated by vibrating with the concrete vibrator augmented by "tapping" of the pile with a sledge.

A few test piles were backfilled with water. The water was poured into the annular space at a temperature of approximately 33°F. Water backfilled piles were provided with protection at the ground surface to prevent entry of foreign material and to provide shading to facilitate pile freezeback. (See Photo No. 27).

#### 7. Discussion of Methods.

a. Steam Thaw Method. Steam thawed pile holes were advanced in the frozen fine grained soils at the Fairbanks Permafrost Research Area without difficulty. It required 10 to 20 minutes to advance a 3/4-in. diameter steam jet to approximately a 20 ft depth in frozen soil. With the steam jet in place, an additional 3 hours of continuous steaming was required to thaw a hole approximately 12-in. in diameter. The water consumption at the boiler during steam thaw operations averaged 60 gal per hour or 180 gal per pile.

Steam thaw methods of pile installation are not generally recommended in regions where permafrost temperatures are marginal, i.e., 28°F to 32°F. The steaming process introduces a large quantity of direct heat and hot water into the soil with a pronounced effect on the existing thermal regime and the resultant pile stability of the pile. Observations of test piles installed in the summer by this method at the Fairbanks Permafrost Research Area have indicated a very slow rate of natural pile freezeback and excessive seasonal heave which may extend over several freezing seasons.

In Arctic regions where ambient temperatures and permafrost temperatures are much colder, the use of steam thaw procedures for pile installations could possibly be accomplished without resultant detrimental effects to the pile stability. In such regions, the pile freezeback would be more rapid and positive.

b. Driving Method. The 8-in. open-end pipe piles were easily driven into permafrost by means of conventional pile driving equipment. The driving time per pile using a drop hammer ranged from 20 minutes for a 4 ft pile embedment in permafrost to 40 minutes for an 8-ft pile embedment. The height of drop of the 1350 lb hammer during driving ranged from 10 to 15-ft with an average of about 13 ft. The blow count ranged from an average of 16 blows for the 1st foot of permafrost penetration to an average of 27 blows for the 8th foot of permafrost penetration.

Under the driving effort of the McKiernan-Terry, No. 7, pile hammer, the driving time per pile was about 5 minutes for a 8 ft pile penetration in permafrost and about 9 minutes for 16-ft. The blow count per foot of pile penetration in permafrost averaged 65 blows per ft from 0 to 4-ft penetration; 99 blows per ft from 5 to 8-ft penetration and 110 blows per ft from 9 to 16-ft penetration.

The pile driving experience at the Research Area demonstrated that driving of steel pipe piles into permafrost is a practical and economical method. Piles can be driven without undue disturbance

to the site, thereby preserving the existing thermal regime in the frozen subsoil. It appears likely that steel pile sections other than pipe could be driven with conventional driving equipment without excessive driving effort. A few extraction tests conducted on driven pipe piles at the Research Area have indicated that full adfreeze bond between driven pipe and frozen soil is developed shortly following the driving; there is little or no increase in the adfreeze bond strength with time. This factor would permit immediate construction on driven piles without any delay for pile freezeback which would be essential for piles installed in pre-formed holes and backfilled with slurry.

There is little factual data presently available regarding adfreeze bond strength for driven piles as compared to identical piles installed in pre-formed holes and frozen back in slurry. Extraction tests conducted on pipe piles at the Research Area, under short term loading procedures, showed an average adfreeze bond strength of about 23 psi for 9 driven piles tested. Similar tests on 5 pipe piles installed in pre-formed holes and frozen back in slurry showed an average adfreeze bond strength of about 27 psi. It is conceivable that small irregularities existing on the surface of a metal pile could cause similar irregularities in the frozen soil mass during driving. With the pile in its final position, the embedded surface area would not necessarily conform exactly to the shape of the soil fracture

resulting from the driving. Minute voids could exist along the pile which would have an appreciable effect on the adfreeze bond strength. Such factors are essentially eliminated when a pile is placed in a pre-formed hole and the annular space carefully backfilled with a slurry. The load carrying capacity and behavior characteristics of piles driven in permafrost requires further study.

Further experimentation is also needed on the feasibility of driving piles in the colder permafrost of the arctic and in soil types other than the prevalent silts at the Research Area.

c. Water Drilling Method. The use of a wash-cutting barrel adapted to a rotary drill for pile installation proved to be laborious and time consuming. A full 8 hour working day was required for installing a single pile to a 16-ft permafrost embedment. The boring process was slowed materially by the necessity of adding drill rod for advancing the hole. The removal of cuttings by washing was also very slow. Considerable time is required for movement and setup of the pumps and water system at each pile location. A large quantity of water was required in the operation for removal of cuttings by washing. Such use of water may greatly disturb the existing thermal regime and result in detrimental effects on the pile stability. This method is not adaptable to cold weather operation due to potential freezing of the water circulation system. Use of anti-freeze or other drilling fluids in lieu of water would introduce conditions in the pile hole non-conducive to effective pile freezeback.

The efficiency of the water drilling method could possibly be improved by providing openings at the top of the cutting barrel to facilitate removal of the cuttings by washing. The cutting barrel as used had a closed steel top and it was necessary to wash the cuttings beneath the cutting teeth to the outside of the barrel for removal.

a. Churn Drilling and Driving Method. Experience at the Research Area has demonstrated that a churn drill or well drilling machine is a practical means for installing small diameter pipe piles to support small buildings and structures on permafrost. Photo No. 28 shows a 20 by 60 ft metal utility building at the Research Area which is supported on 27 four inch diameter steel pipe piles. The piles were installed to approximately a 16-ft depth in permafrost using a No. 40 Cyclone churn drill. The weight of the churn drill drive tools was approximately 625 lbs and the height of drop 24 to 30-in. in driving. Installation time per pile was approximately 2 hours, including drilling of a pilot hole and subsequent driving of the pile. Other 4-in. pipe pile foundations have been installed at the Research Area for supporting fuel storage tanks and other utilities.

The Cyclone churn drill is capable of driving 4-in. pipe from a 15 to 20-ft depth in permafrost without benefit of a pilot hole. A pilot hole was used for the Utility Building pile installations to prevent undue damage to the pile tops. The weight of the drive tools may be adjusted as desired by addition or removal of standard tool sections.

from the "string of tools." Churn drills of larger capacity than the No. 40 Cyclone Drill, should be equally effective for driving pipe of larger diameter than 4-in. Churn drilling of a pilot hole prior to driving the pipe is not essential but will expedite the installation work.

e. Dry Augering Method. Dry augering of pile holes in the frozen fine grained soils at the Fairbanks Permafrost Research Area was accomplished quickly and efficiently. Approximately 20 minutes was required to auger a pile hole 18-ft into permafrost. Hole diameters ranged from 10 to 18 in. and the size of the hole appeared to have little effect on the augering rate. Power auger operators have stated that special auger bits with carbide cutters have been highly successful for augering all types of permafrost soils. This particular type of auger bit is now known as the "Alaska Type Bit."

The dry augering method of pile installation is an efficient and economical method for installing large diameter piles or large size structural shapes. This method has the distinct advantage of providing pile holes without the use of water, a highly desirable characteristic in the preservation of the existing thermal regime. Power augers are generally truck or tractor mounted which provide desirable equipment mobility. The dry augering method has been used effectively on large scale pile foundation projects of the Corps of Engineers at remote Alaska sites. At one

particular project in Arctic Alaska, approximately 500 wood piles were installed by the dry auger method to support a structure about 230 by 260 ft in plan. Pile holes 20-in. in diameter were augered to a 31 ft depth in frozen silt and ice. The permafrost temperature was in the range of 25°F and the augering time was approximately 35 minutes per hole.

The application of the dry augering method in regions where permafrost temperatures are substantially colder than 25°F, such as the Point Barrow vicinity, requires further experimentation.

f. Pile Backfill Methods. The backfill of piles installed in pre-formed holes in permafrost is of paramount importance to the stability of the pile and ultimate load bearing capacity. Backfill material used for test pile installations at the Research Area has consisted primarily of silt-water slurry. The mixing and placing of slurry by manual procedures is time consuming and laborious and is not recommended for installation of any sizeable number of piles. A conventional concrete mixer mounted on a truck for mobility provides a highly efficient method for slurry mixing. On large scale pile installation projects, the capacity of the mixer should be sufficient to provide slurry backfill material for several piles in a single batch. Pile backfill should be accomplished in vertical lifts of 3 to 4-ft with each lift carefully consolidated by rodding or vibration to assure elimination of void spaces along the pile. A small spud type concrete vibrator is an

effective means of consolidating slurry during placement. Pile holes should be formed large enough to permit ready access of a vibrator head in the annular space between the pile and wall of the hole.

All possible precautions should be taken during pile backfill procedures to protect the existing thermal regime in the subsoil and thus facilitate the pile freezeback. Setting of the pile and placement of backfill material should be accomplished as soon as practical after completion of the pile hole. Slurry backfill material should be mixed and placed at the coldest possible temperature consistent with thorough mixing. Cuttings from augered holes can be mixed with cold water to produce cold temperature slurries. In mixing frozen auger cuttings with water at approximately 33°F, it was found that an excessive mixing time was required to thaw the frozen chips and produce consistent slurry. Subsequent tests showed that mixing of frozen cuttings with water at a temperature of approximately 70°F produced a consistent slurry in about 5 minutes of mixing time with a resultant slurry temperature of approximately 32.5°F. Test piles installed in dry augered holes at the Fairbanks Permafrost Research Area, which were backfilled with machine mixed slurry at a temperature of about 32.5°F at placement, demonstrated complete freezeback under natural conditions in a period of 5 to 7 days. It is believed a frozen chip-slurry mixture would be more effective for freezeback providing the slurry would flow into the annular space.

More experimentation is needed in types of pile backfill materials and in methods of placement.

8. Conclusions. The following conclusions are based on experiences with test piles at the Fairbanks Permafrost Research Area.

a. There is substantial evidence that the stability and load bearing capacity of piles installed in permafrost are influenced by the method of pile installation. Piles installed in steam thawed holes, under summer conditions have demonstrated substantial heave extending over several freezing seasons. Driven piles have indicated a smaller adfreeze bond strength than similar piles installed in drilled or augered holes and frozen back in soil-water slurry.

b. Pile holes can be readily advanced in frozen fine grained soils using steam thaw procedures. Steam thaw procedures are not recommended in regions of marginal permafrost temperatures, i. e., 28°F to 32°F. Under marginal permafrost conditions, pile freezeback in steam thawed holes is slow and pile heave excessive. Steam thaw pile installation may be accomplished without detrimental effects in Arctic regions where ambient temperatures and permafrost temperatures are much colder and the resultant pile freezeback more rapid and positive.

c. Driving steel pipe piles in frozen fine grained soils with marginal permafrost temperatures is feasible and practical with conventional pile driving equipment. Drop hammer and power hammer type of driving methods are equally effective and result in minimum disturbance

to the existing thermal regime. More experimentation is required to establish the feasibility of driving other steel shapes and driving of piles in colder permafrost and other soil types.

d. The water drilling method of pile installation utilizing a special cutting barrel adapted to a rotary drill is not an efficient method for installing piles in permafrost. A large quantity of drilling water is required which is undesirable in preserving the thermal regime, especially in regions of marginal permafrost temperatures. Movement and setup of pumps and allied drilling equipment is time consuming. The method is not adaptable to cold weather operations due to potential freezing of the water circulating system. Efficiency of the method could possibly be improved with further experimentation in the design of cutting barrels.

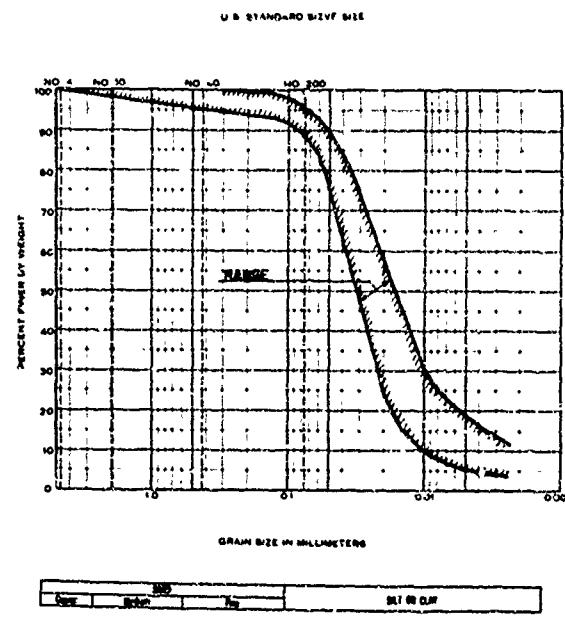
e. A common well drilling machine or churn drill is an effective means for driving small diameter pipe piles in frozen silt soils. The installation work is greatly facilitated by driving the pipe through a pilot hole predrilled with the same machine. The churn drill method provides an economical means for constructing pile foundations for supporting small buildings and structures.

f. The dry auger method is an efficient and economical means for installing large diameter piles in large scale operations. This method has the distinct advantage of providing pile holes without the use of water. With reasonable backfill precautions, foundation

piles can be installed by the dry auger method without undue disturbance to the existing thermal regime. This method has been employed successfully on large scale Corps of Engineers construction at remote Alaska sites.

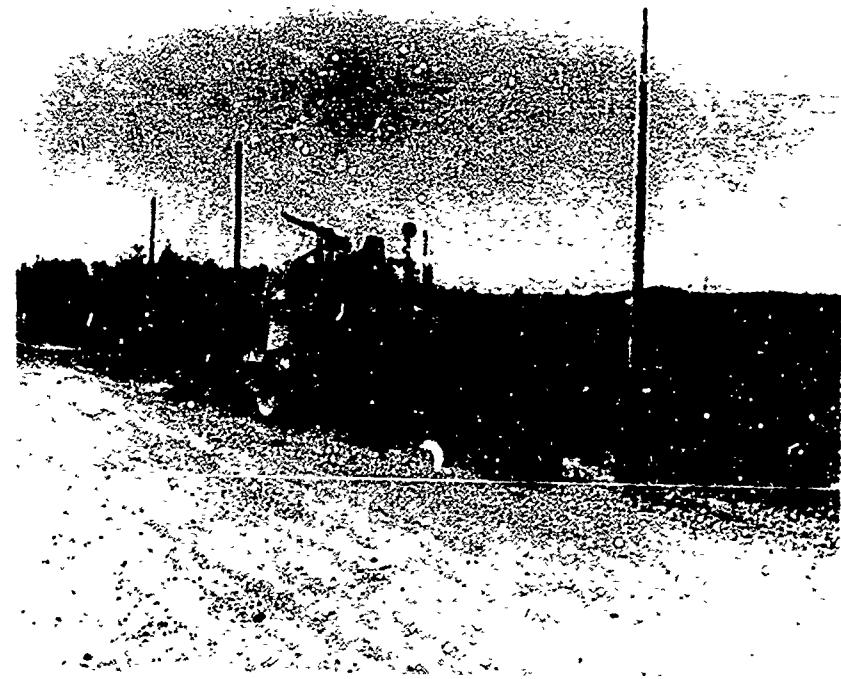
g. Proper pile backfill procedures are of utmost importance to the resultant stability of the pile and load bearing capacity. Soil-water slurries can be mixed and placed effectively using conventional concrete equipment and procedures. Backfill materials should be thoroughly rodded and/or vibrated during placement to eliminate void spaces along the pile. Rate of pile freezeback is dependent on several factors including temperature of the pile, placement temperature of the backfill material, and temperature of the existing permafrost.

Studies of foundation piles in permafrost are continuing at the Fairbanks Permafrost Research Area.



GRADATION RANGE  
ON EIGHT SOIL SAMPLES

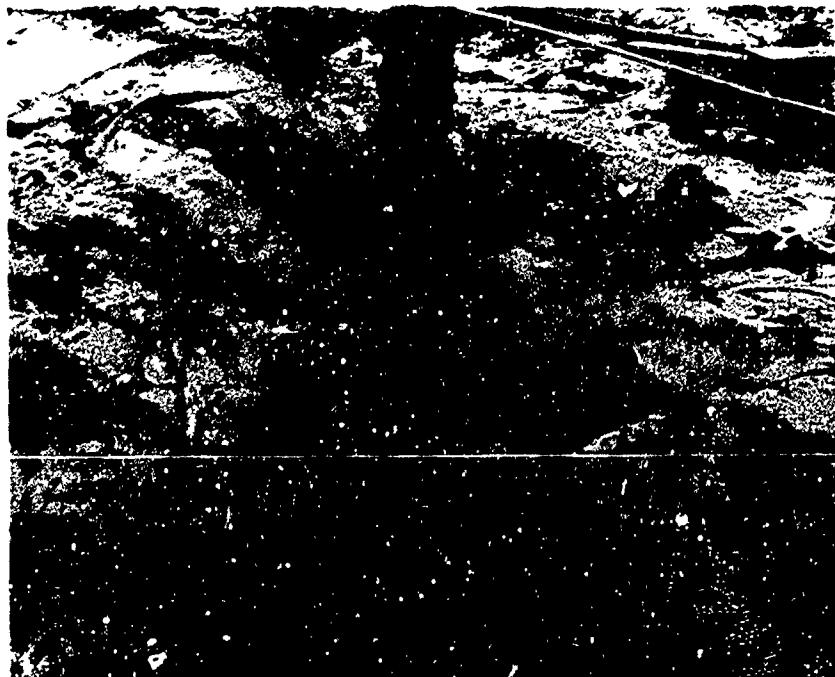
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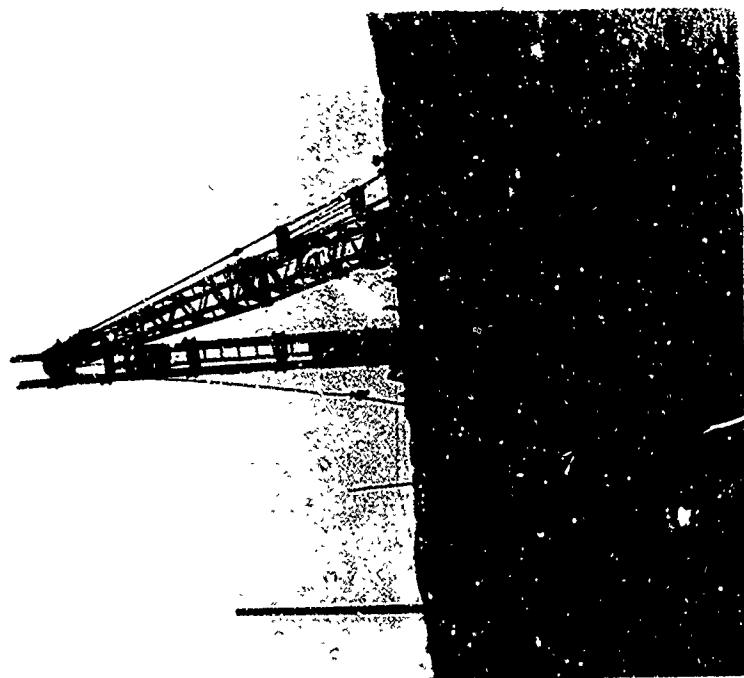
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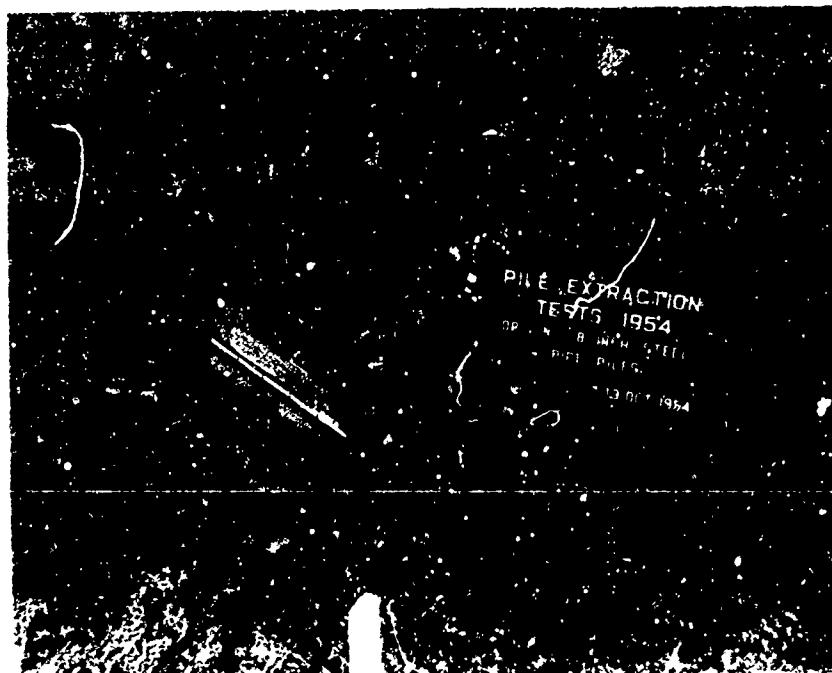
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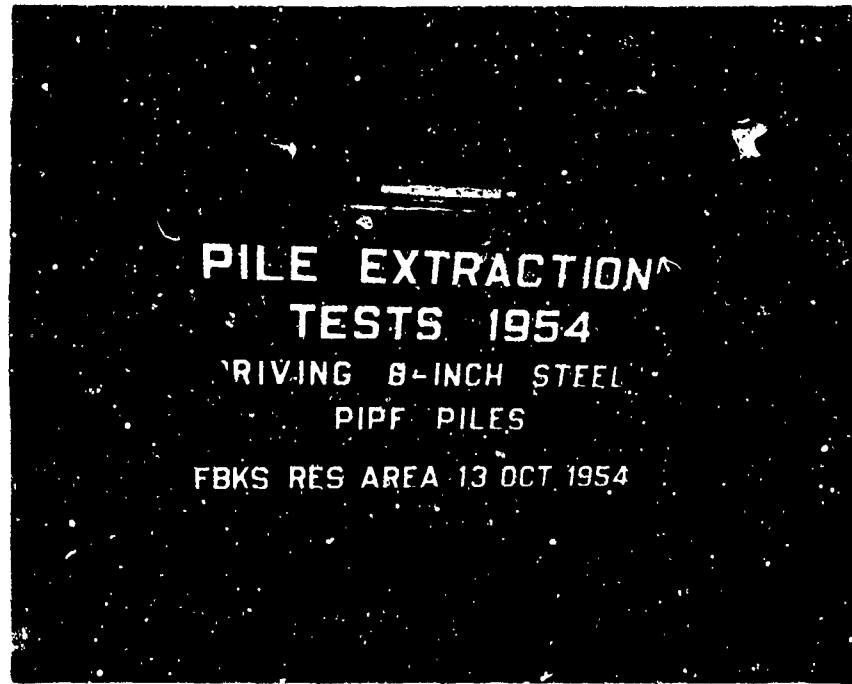
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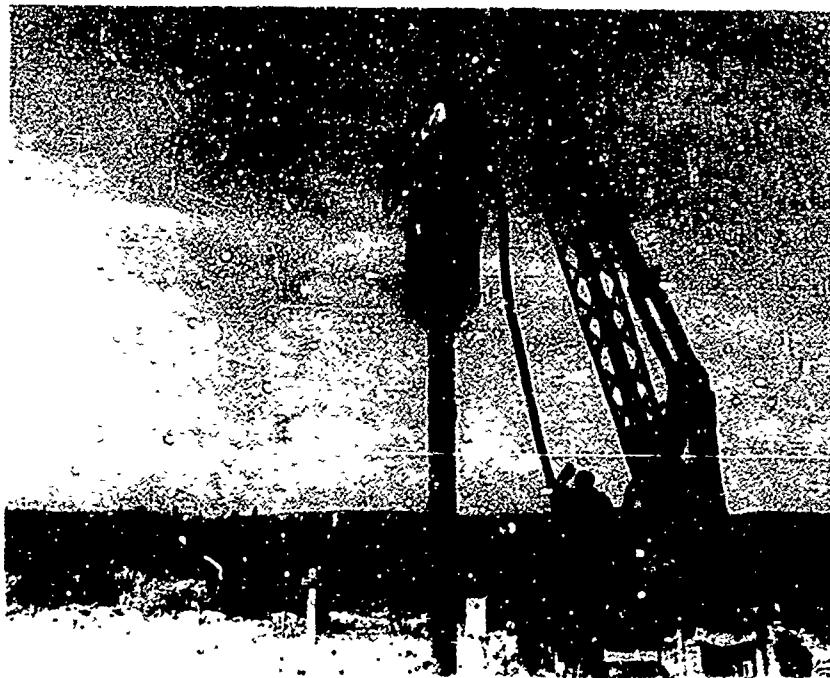
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Photograph No. 6



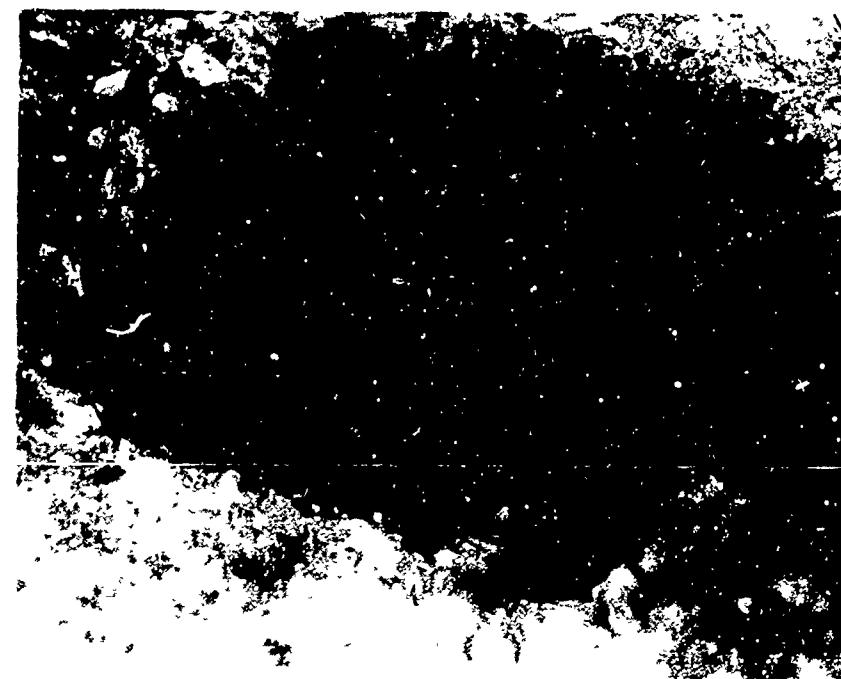
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Photograph No. 8



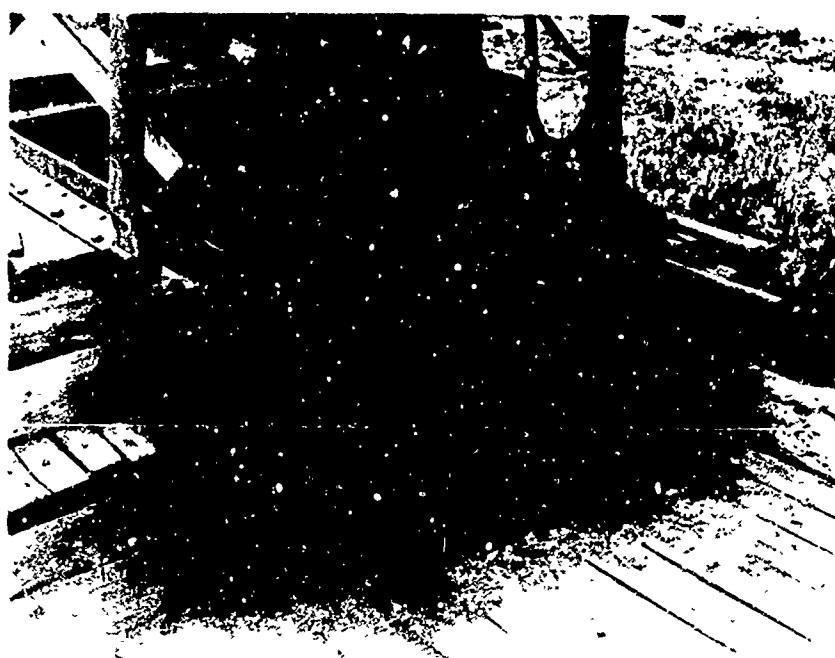
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Photograph No. 10



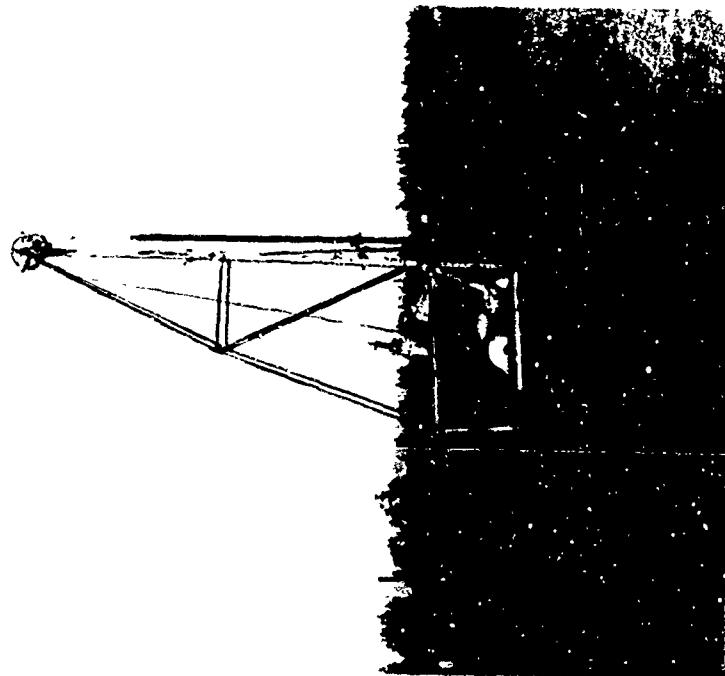
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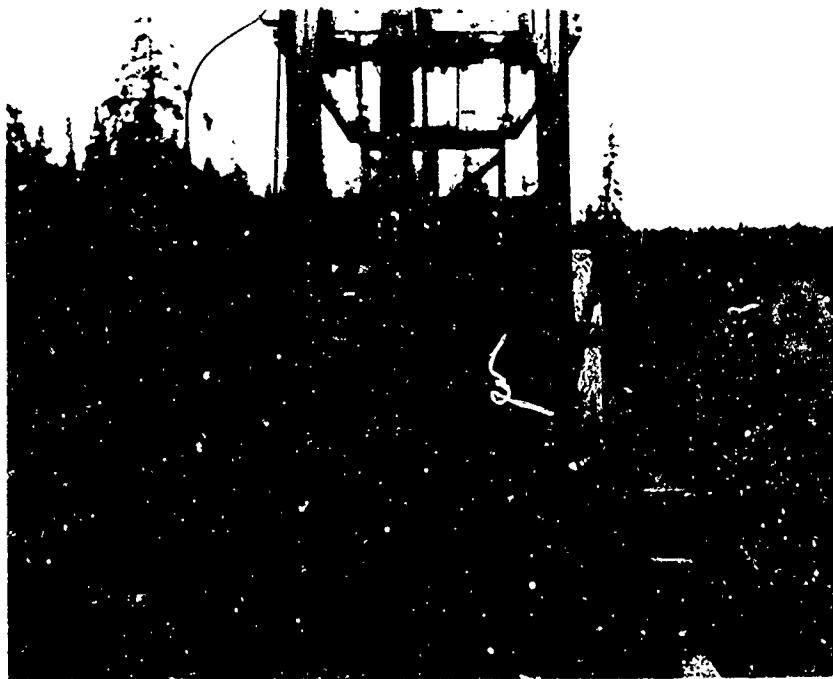
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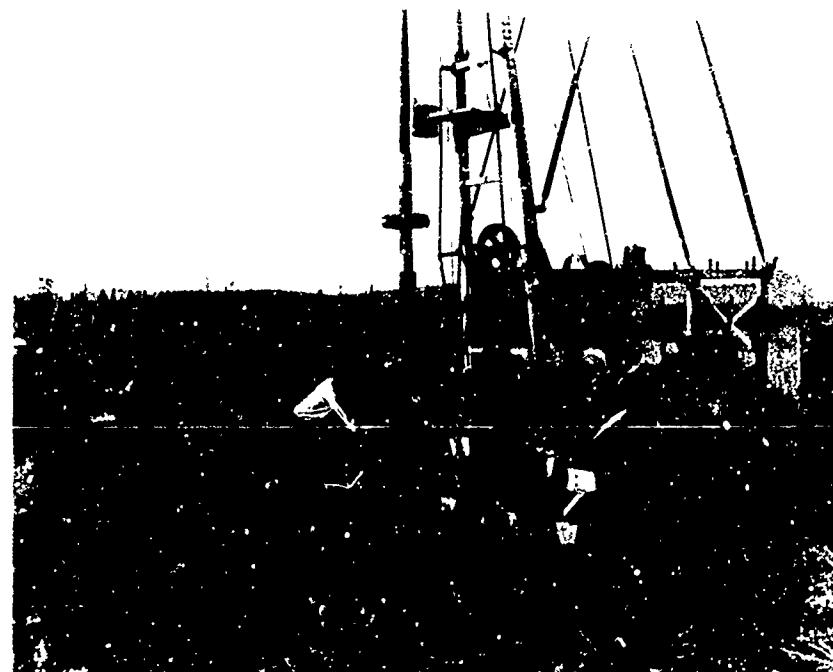
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Photograph No. 14



Photograph No. 15



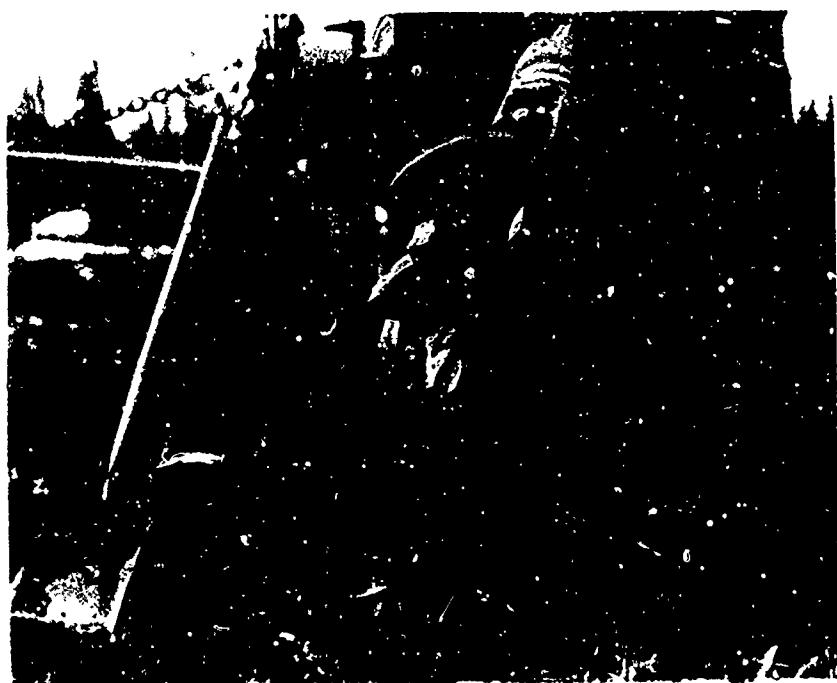
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Photograph No. 17



Photograph No. 18



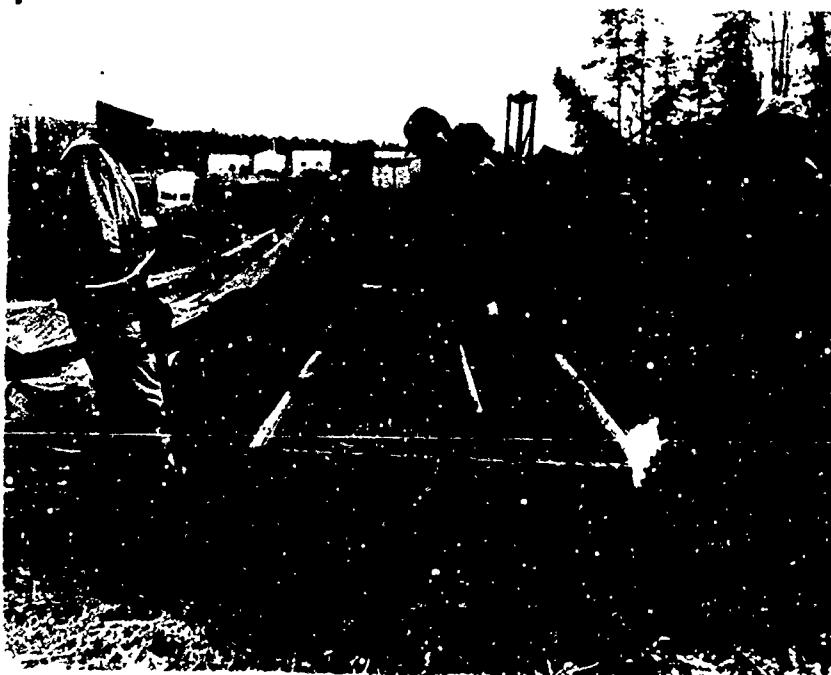
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Photograph No. 20



Photograph No. 21



Photograph No. 22



Photograph No. 23



Photograph No. 24



Photograph No. 25



Photograph No. 26



Photograph No. 27



Photograph No. 28

END

DATE

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